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Centre number

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Candidate number

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Surname

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A-level PHYSICS

Paper 3

Section B Turning points in physics

Monday 3 June 2019

Afternoon

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
TOTAL	

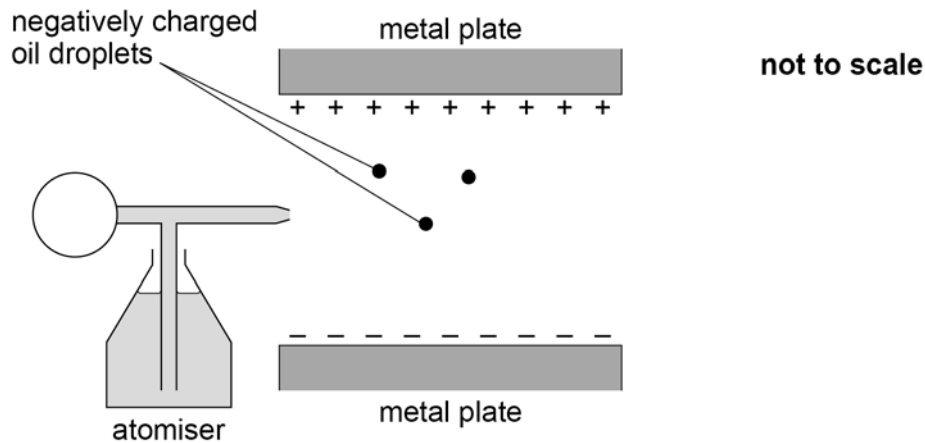


J U N 1 9 7 4 0 8 3 B D 0 1

Section B

Answer **all** questions in this section.

0 1

Figure 1 shows an experiment to measure the charge of the electron.**Figure 1**

Negatively charged oil droplets are sprayed from the atomiser into the gap between the two horizontal metal plates. A potential difference is applied between the metal plates.

One of the droplets remains stationary.

0 1 . 1

Identify the forces acting on the stationary droplet.
In your answer you should state the relationship between the forces.

The upthrust on the droplet due to the air it displaces is negligible.

[2 marks]

Two forces act: the weight (gravitational force) of the droplet acting vertically downwards, and the electric (electrostatic) force due to the electric field between the plates acting vertically upwards.

These forces are equal in magnitude and opposite in direction: weight = electric force, so $mg = QV/d$.



0 1 . 2

The potential difference between the plates is changed to zero and the droplet falls at a terminal velocity of $1.0 \times 10^{-4} \text{ m s}^{-1}$.

The density of the oil is 880 kg m^{-3}

The viscosity of air is $1.8 \times 10^{-5} \text{ N s m}^{-2}$

Show that the radius of the droplet is about $1 \times 10^{-6} \text{ m}$.

Assume that the droplet is spherical.

[3 marks]

At terminal velocity, weight = viscous drag: $mg = 6\pi\eta rv$

mass $m = \rho \times \text{volume} = (4/3)\pi r^3 \rho$

so $(4/3)\pi r^3 \rho g = 6\pi\eta rv$

rearranging: $r^2 = 18\eta v / 4\rho g = 9\eta v / 2\rho g$

$r^2 = (9 \times 1.8 \times 10^{-5} \times 1.0 \times 10^{-4}) / (2 \times 880 \times 9.81)$

$r^2 = 9.4 \times 10^{-13} \text{ m}^2$

$r = \sqrt{9.4 \times 10^{-13}} = 9.7 \times 10^{-7} \text{ m}$

$9.7 \times 10^{-7} \text{ m}$, which is about $1 \times 10^{-6} \text{ m}$

Question 1 continues on the next page

Turn over ►



0 1 . 3

The potential difference between the plates is restored to its initial value and the droplet becomes stationary.

The charge on the droplet is $-4.8 \times 10^{-19} \text{ C}$.

A student suggests that, if the droplet splits into two spheres of equal size, both spheres would remain stationary.

Deduce whether this suggestion is correct.

[3 marks]

Number of excess electrons on the droplet = $4.8 \times 10^{-19} / 1.6 \times 10^{-19} =$

3 electrons.

If the droplet splits into two equal spheres, each has half the mass, so half the weight. For each half to stay stationary in the same field, each would need half the charge, $2.4 \times 10^{-19} \text{ C}$, which is $1.5e$.

But charge is quantised (it comes in whole multiples of e), so the 3 electrons cannot be split equally. One sphere would have $1e$ ($1.6 \times 10^{-19} \text{ C}$) and the other $2e$ ($3.2 \times 10^{-19} \text{ C}$).

So the electric force on one sphere would be less than its weight (it falls) and on the other greater than its weight (it rises). It is not possible for both spheres to remain stationary, so the student is wrong.

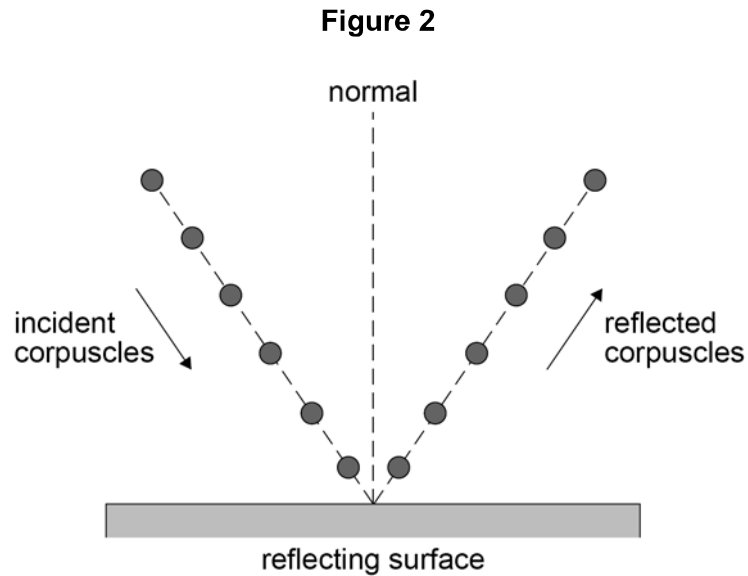
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0 2

Newton used a corpuscular theory of light to explain reflection.

Figure 2 shows how corpuscles would reflect from a horizontal surface.



0 2 . 1

What happens to the horizontal and vertical components of the velocity of the corpuscles, according to the theory, when they are reflected?

Tick (✓) **one** box.

[1 mark]

Horizontal component of velocity	Vertical component of velocity	Tick the correct box
Unchanged	Changed	✓
Changed	Unchanged	
Unchanged	Unchanged	
Changed	Changed	

Question 2 continues on the next page

Turn over ►



0 2 . 2

Newton used the corpuscular theory to explain the refraction of light at an interface between air and water.

Huygens used the wave theory to explain the refraction of light at the interface.

Discuss the evidence that led to the rejection of Newton's corpuscular theory.

In your answer you should include

- how each theory explains refraction
- how experimental evidence led to the acceptance of the wave theory.

[6 marks]

Newton's corpuscular theory: light is made up of tiny particles called corpuscles. When the corpuscles approach the water surface, a force of attraction acts on them towards the water. This attraction only acts at the interface (boundary), and it acts at right angles (normal) to the surface.

So only the vertical component of the velocity (momentum) of the corpuscles changes at the interface: the vertical component increases while the horizontal component stays the same. This causes the change in direction, so the corpuscles bend towards the normal. This means Newton's theory predicts that light travels faster in water than in air.

Huygens' wave theory: light is a wave. A wavefront is incident on the interface at an angle. Every point on the wavefront acts as a source of secondary wavelets. The wavelets that enter the water first travel more slowly in the water than the wavelets still in the air, so they travel a shorter distance in the same time.

The new wavefront is the tangent (envelope) to the secondary wavelets, so it is turned. The slowing down of the wavelets causes the change in direction, so the light bends towards the normal. So Huygens' theory predicts that light travels more slowly in water than in air.

Evidence: the two theories made opposite predictions about the speed of light in water. When the speed of light in water was measured (by



Foucault and Fizeau in the mid 1800s), it was found to be slower than in air, which supported Huygens' prediction and disproved Newton's. Also, light was observed to show interference. In Young's double slit experiment, light produced bright and dark fringes. Interference (and diffraction) can be explained by Huygens' wave theory, as waves superpose constructively and destructively, but cannot be explained by Newton's corpuscular theory, which predicted only two bright bands. Because of this experimental evidence, Newton's corpuscular theory was rejected and the wave theory was accepted.

Question 2 continues on the next page

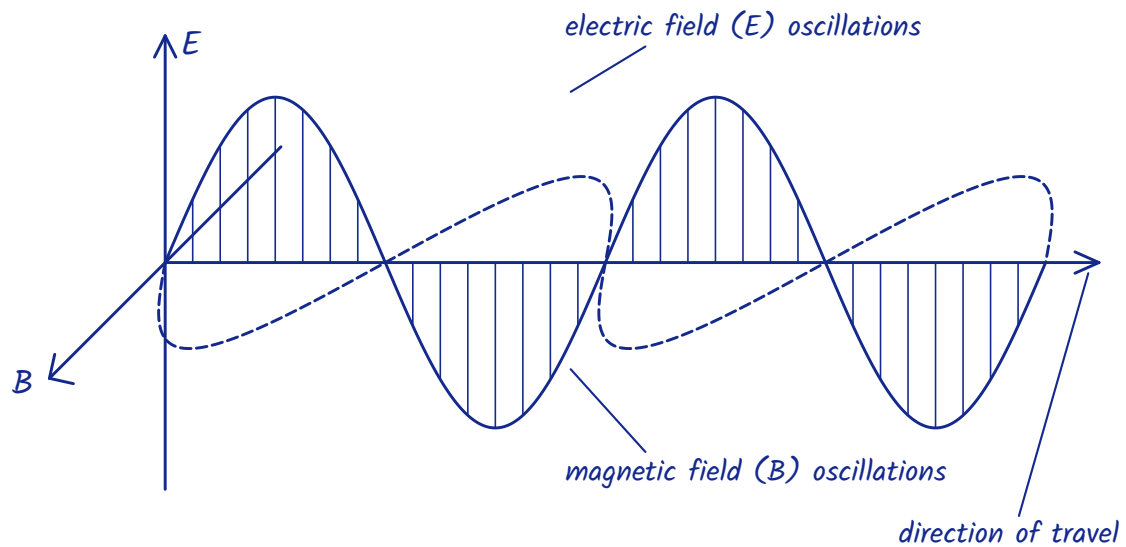
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0 2 . 3 Light is now known to behave as an electromagnetic wave.

Describe a plane-polarised electromagnetic wave travelling through a vacuum.
You may wish to draw a labelled diagram.

[3 marks]



Plane-polarised: the electric field oscillations (E) are in one plane only,
and the magnetic field oscillations (B) are in one plane only.

The electric and magnetic fields are perpendicular to each other and
both are perpendicular to the direction of travel (transverse). They are
in phase with each other, and the wave travels at $c = 3.0 \times 10^8 \text{ m s}^{-1}$.



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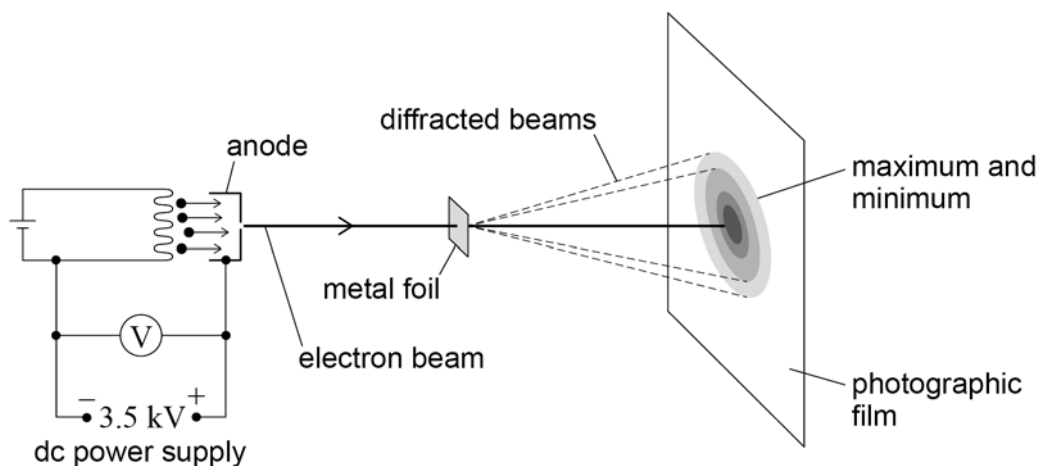
0 3

Figure 3 shows part of the apparatus used to investigate electron diffraction.

Electrons were accelerated through a potential difference to form a beam which was then incident on a thin metal foil.

Regions of maximum and minimum intensity formed on a photographic film behind the foil.

Figure 3



0 3 . 1

State de Broglie's hypothesis.

[2 marks]

All matter particles (e.g. electrons) have a wave-like nature (wave-like properties).

The wavelength associated with a particle is $\lambda = h / p$, where h is the Planck constant and p is the momentum of the particle ($p = mv$).

0 3 . 2

The voltmeter in **Figure 3** shows a reading of 3.5 kV.

Determine whether this voltmeter reading is consistent with a de Broglie wavelength for the electrons in the beam of about 0.02 nm.

[2 marks]

$$\lambda = h / \sqrt{(2meV)} = 6.63 \times 10^{-34} / \sqrt{(2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 3500)}$$

$$\lambda = 6.63 \times 10^{-34} / 3.19 \times 10^{-23} = 2.1 \times 10^{-11} \text{ m} = 0.021 \text{ nm}$$

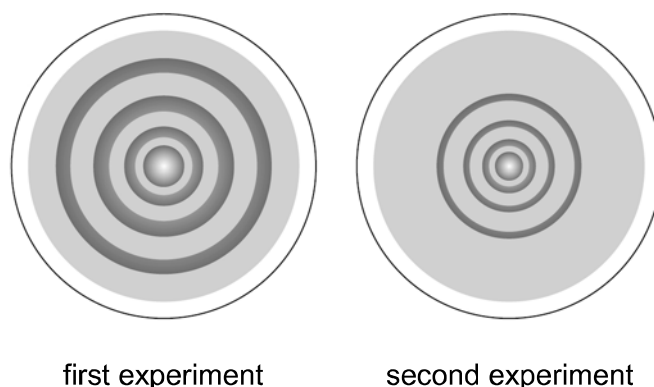
0.021 nm is about 0.02 nm, so the 3.5 kV reading is consistent.



0 3 . 3

The experiment is repeated using a similar arrangement to that shown in **Figure 3**. **Figure 4** shows the diffraction patterns from the two experiments.

Figure 4



State and explain **two** independent changes that could be made to the arrangement in **Figure 3** to produce the result shown for the second experiment in **Figure 4**.

[4 marks]

First change Increase the (accelerating) potential difference.

The electrons gain more kinetic energy, so their speed and momentum

increase, so their de Broglie wavelength ($\lambda = h/mv$) is smaller. A

smaller wavelength is diffracted through smaller angles, so the rings are
closer together (narrower).

Second change Use a metal foil (target) with a greater spacing between
the atoms.

For the same wavelength, a larger separation between atoms gives

smaller diffraction angles, so the maxima are closer together and the
rings are narrower.



0 4

Table 1 shows data of speed v and kinetic energy E_k for electrons from a modern version of the Bertozzi experiment.

Table 1

$v / 10^8 \text{ m s}^{-1}$	E_k / MeV
2.60	0.5
2.73	0.7
2.88	1.3
2.96	2.6
2.99	5.8

0 4 . 1

Classical mechanics predicts that $E_k \propto v^2$.

Deduce whether the data in **Table 1** are consistent with this prediction.

[2 marks]

E_k / v^2 (in MeV per $10^{16} \text{ m}^2 \text{ s}^{-2}$):

$$v = 2.60: 0.5 / 2.60^2 = 0.074$$

$$v = 2.73: 0.7 / 2.73^2 = 0.094$$

$$v = 2.88: 1.3 / 2.88^2 = 0.157$$

$$v = 2.96: 2.6 / 2.96^2 = 0.297$$

$$v = 2.99: 5.8 / 2.99^2 = 0.649$$

The constant E_k / v^2 is not constant: it increases from 0.074 to 0.649

as v increases, so E_k is not proportional to v^2 .

The data are not consistent with the classical prediction.



0 4 . 2

Discuss how Einstein's theory of special relativity explains the data in **Table 1**.**[4 marks]**

The speed of the electrons has an upper limit: as E_k increases, v increases less and less and never reaches c (E_k / v^2 increases).

Explanation: in special relativity, the mass of the electron increases as its speed increases, $m = m_0 / \sqrt{1 - v^2/c^2}$.

As v approaches c , the mass approaches infinity, so at these speeds the increase in mass is significant.

So near c , increases in E_k are mainly due to the increase in mass, not speed, and E_k tends to infinity as v approaches c .

0 4 . 3

Calculate, in J, the kinetic energy of one electron travelling at a speed of $0.95c$.**[3 marks]**

$$\text{Rest energy } E_0 = m_0 c^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.2 \times 10^{-14} \text{ J}$$

$$\text{Total energy } E = m_0 c^2 / \sqrt{1 - v^2/c^2} = 8.2 \times 10^{-14} / \sqrt{1 - 0.95^2}$$

$$E = 8.2 \times 10^{-14} / 0.312 = 2.6 \times 10^{-13} \text{ J}$$

$$E_k = E - E_0 = 2.6 \times 10^{-13} - 8.2 \times 10^{-14}$$

$$E_k = 1.8 \times 10^{-13} \text{ J}$$

kinetic energy = 1.8 × 10⁻¹³ J

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END OF QUESTIONS

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